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Geosynchronous Electron Fluxes During an MHD Substorm

Development and Testing of a New Particle Tracing Model

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Particle Tracing Helps Bridge the Gap Between MHD and Kinetic Modeling

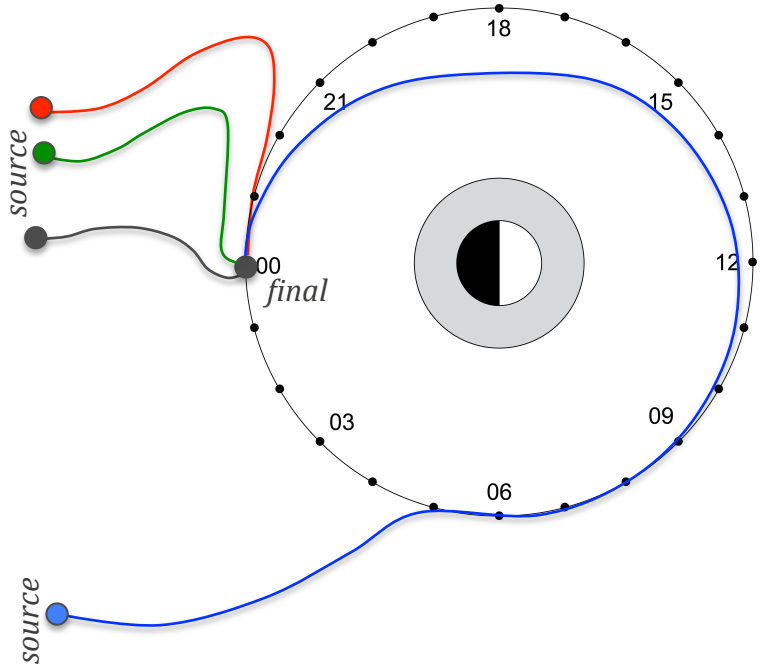
"What we've got here is failure to communicate."

- Reconnection occurs in the tail at ~20 R_E
- Injections are observed at ~6.6 R_E
- Both of these locations can be covered by kinetic physics:
  - *ePIC* in the tail
  - *RAM-SCB* at GEO

In between? MHD w/an implicit Maxwellian assumption and very little energy/ pitch angle info (more moments, better info of course…)

Particle tracing propagates kinetic information through MHD space.

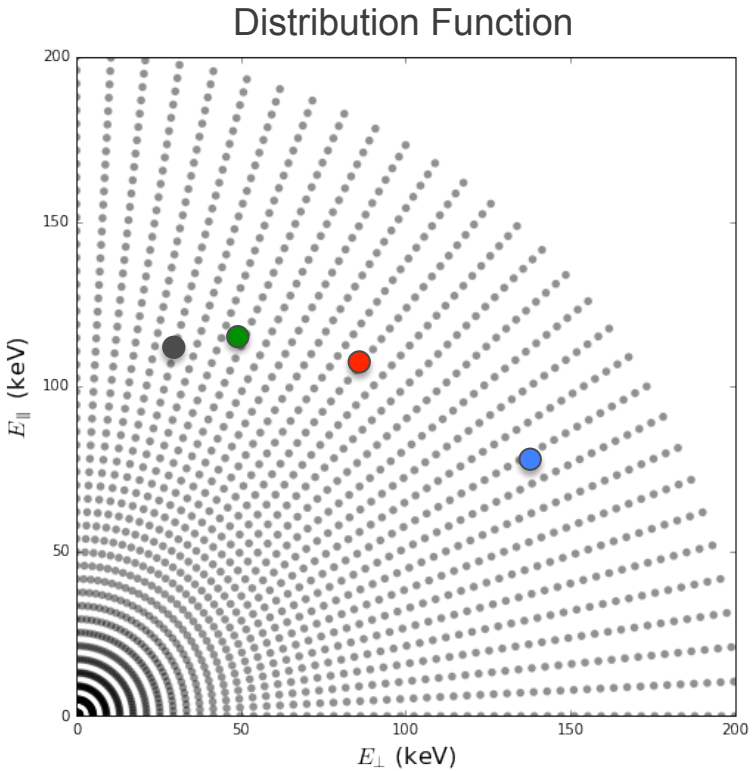
Fluxes Can Be Efficiently Calculated with Backwards Liouville Tracing (though forward's not too bad either)



$$\frac{df}{dt} = \left(\frac{\delta f}{\delta t}\right)_{discrete}$$

Discreteness Effects

$$f(E_{source}, \alpha_{source}) = f(E_{final}, \alpha_{final})$$



It's Challenging to Characterize the Source Populations

Method 1: Empirical Distributions

Observations provide guidance

- *Birn et al.* [1997 et sub.] Tail κ distribution
- THEMIS measurements

Is a single model globally appropriate?

Method 2: MHD Moments

Density and pressure are available, but not distribution function?

- *Tsyganeko & Mukai* [2003]
- SWMF model output

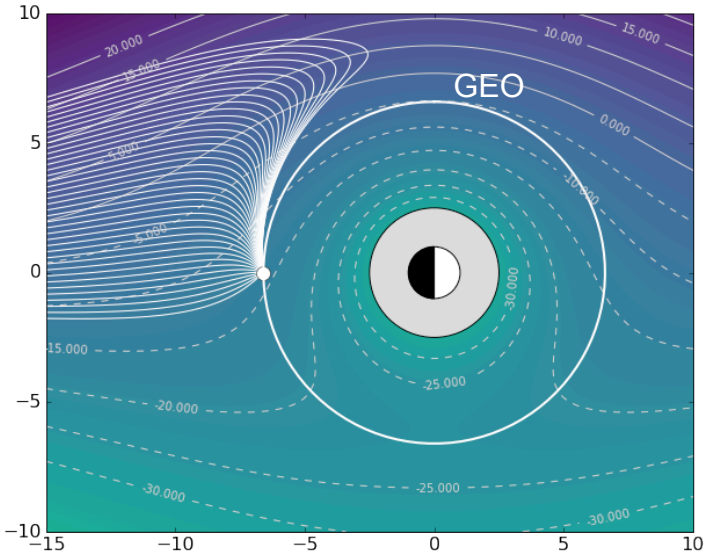
How many moments do you need to get the "right" distribution?

Hybrid Approach: Test distributions used in moment models and optimize parameters to reproduce empirical data.

Source Investigation with Empirical Models:
Dipole ***B***, Volland-Stern ***E***, and TM03 Plasma Moments

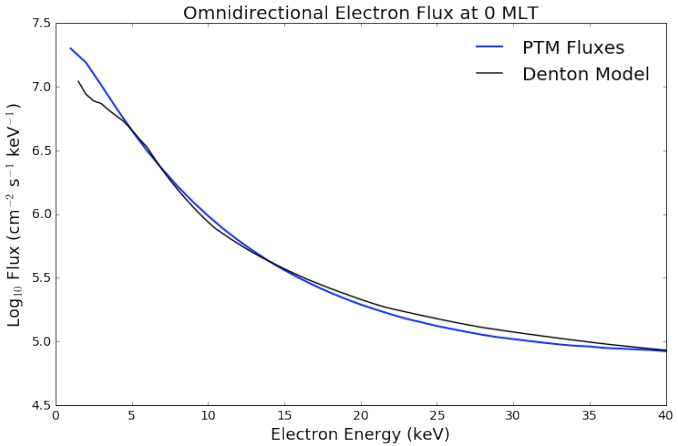
Denton et al. [2015] Geosynchronous Flux Model

- 1-40 keV e^- fluxes at GEO

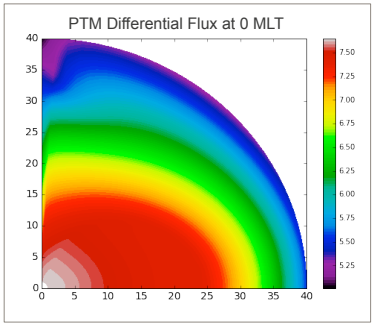


Tsyganenko & Mukai [2003] Plasma Sheet Model

- Density and temperature as a function of (x,y) in plasma sheet
- *Maxwellian* distribution function
  (not generally the *right* choice, but here it works)

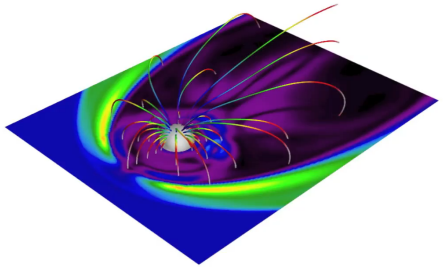


$$\frac{W_f}{W_i} \approx \frac{r_i^2}{r_f^2}\left(r_i \sin^2\alpha + r_f \cos^2\alpha\right)$$



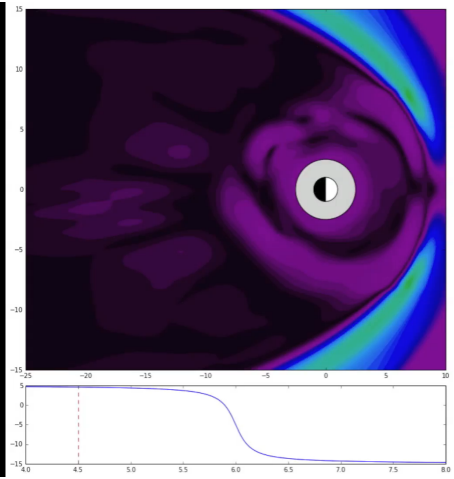
Overview of the SWMF & RAM-SCB “Ideal Substorm”

Field Lines (5 min. cadence)



Until you sample fast enough, *how fast* you sample the fields is going to affect your solution

Total ***E*** in the equatorial plane

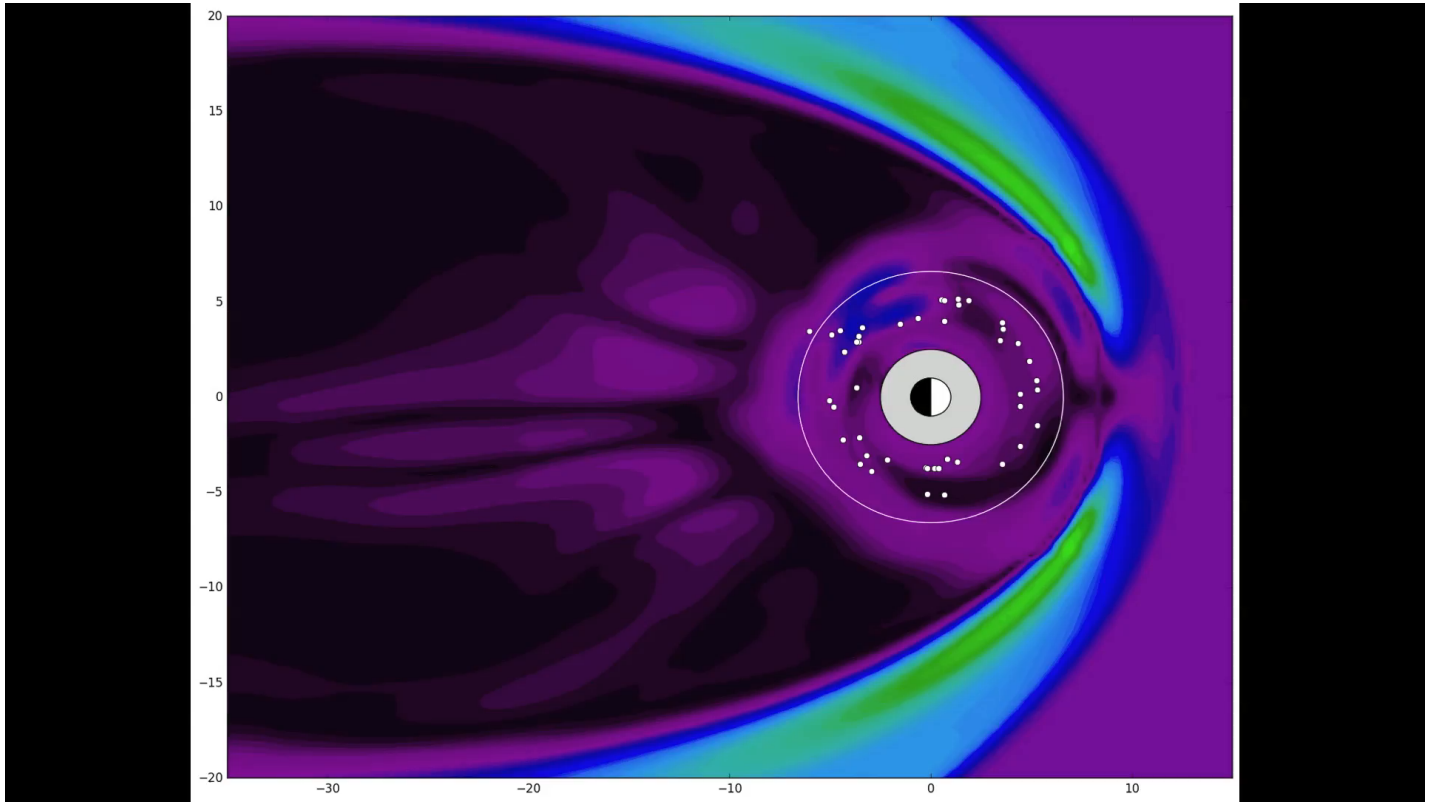


Event is IMF B_z driven

Ideal doesn’t mean simple, and stuff happens (annoyingly) fast.

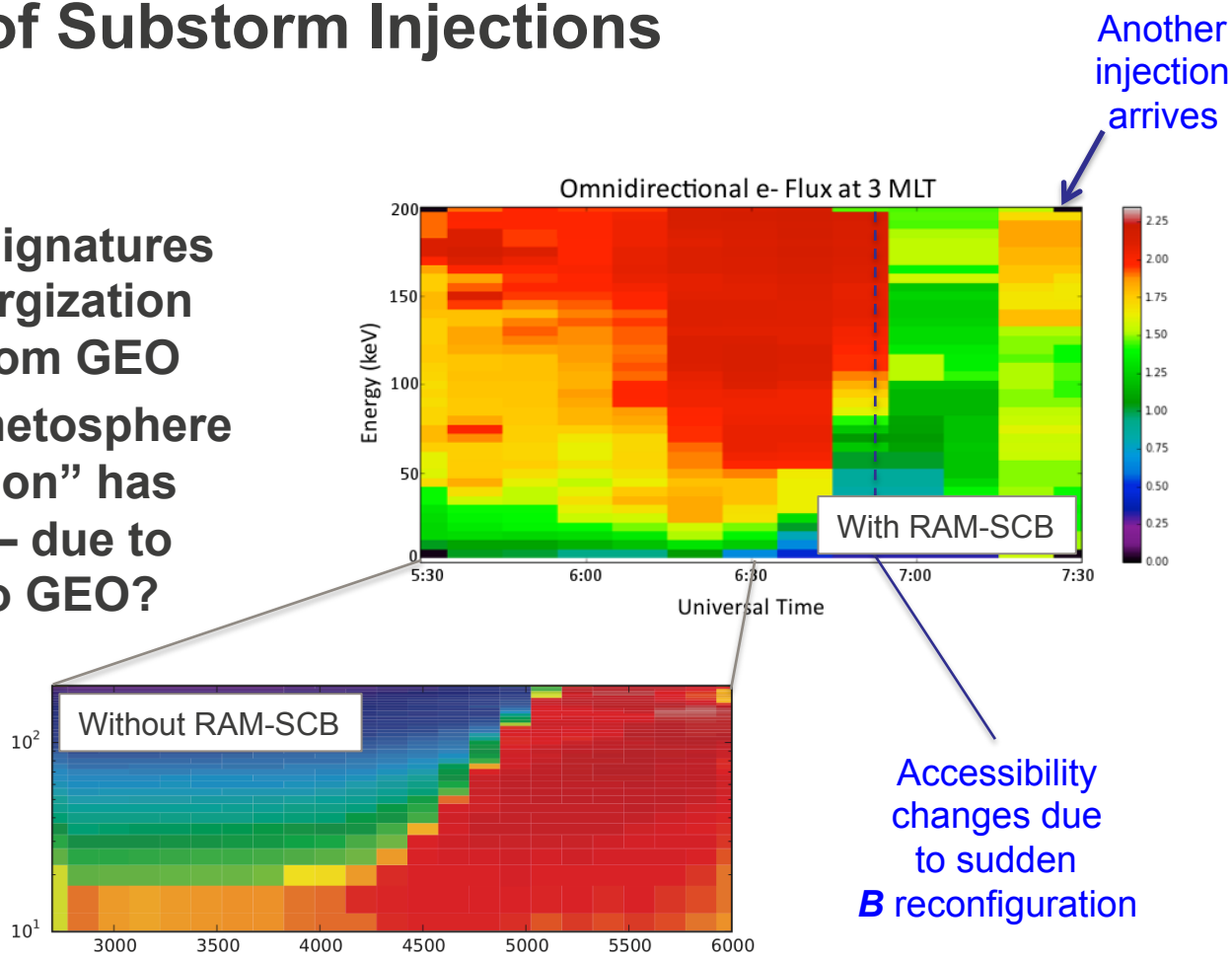
Backtrace Simulation Example

(the movie goes forward in time)



Particle Tracing of Substorm Injections

- **Energy-dispersed signatures are produced if energization takes place away from GEO**
- **Without inner magnetosphere (RAM-SCB), "injection" has inverse dispersion – due to mapping of IMF *E* to GEO?**



Summary

- **Backwards tracing is a very promising tool for modeling dynamic fluxes and communicating kinetic information through an MHD model**
- **But there are a complications**
  - Time and space sampling is important
  - Source populations are not always well-characterized
    - Tail? Lobe? Solar wind???
    - Kappa, Maxwellian?

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EXTRA SLIDES

SHIELDS/PTM is Designed for Accuracy

(speed will have to come later)

- **Hybrid full orbit/guiding center with automatic switching based on electromagnetic field gradients**
- **3rd order spatial interpolation using tricubic splines**
  - Continuous 1st derivatives for GC equations
- **Multiple choices of integrator:**
  - Fixed step Runge-Kutta
  - Adaptive Runge-Kutta (RKSuite)
  - Adaptive Bulirsch-Stoer
  - Variable order predictor-corrector (VODE)
  - Boris method (phase space volume-preserving)
  - Investigating use of symplectic integrators